Long-term Experience with MR Upgrades

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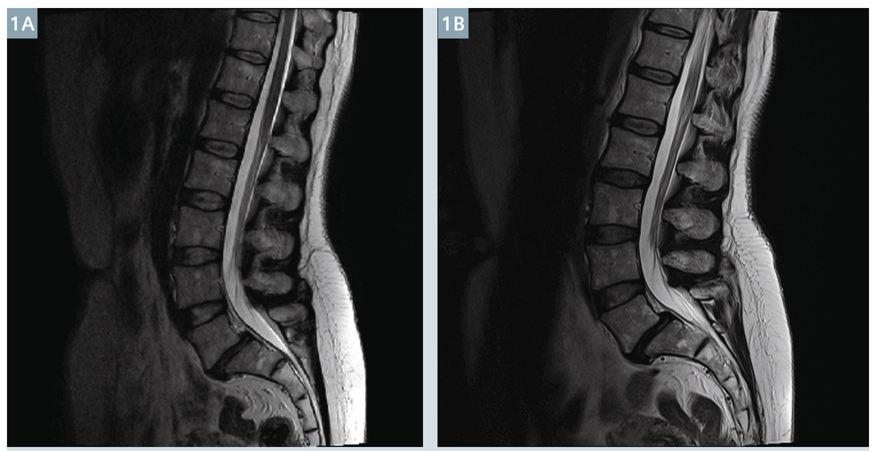
In this article we share some of our experiences over the last few years with MR upgrades.

The MRI AG Spital Maennedorf is located beside Lake Zurich in Switzerland and is one of the leading MR-centers in the region. With its close relationship to the academic hospital Maennedorf and to specialized practitioners with a variety of subspecialties including Orthopedics, Trauma-/General-/Hand- and Neuro-Surgery, Neurology, Psychiatry, Gastroenterology, Urology, Gynecology and Angiology we receive requests for MR examinations all over the body ("from head to toe"). We therefore need an MRI scanner able to perform all kinds of examinations at a very high level. Our referring physicians recognize the high quality of our work and our participation in radiology boards and meetings (e.g. European School of Radiology). Without the proper technical equipment it would not be possible to sustain this high level.

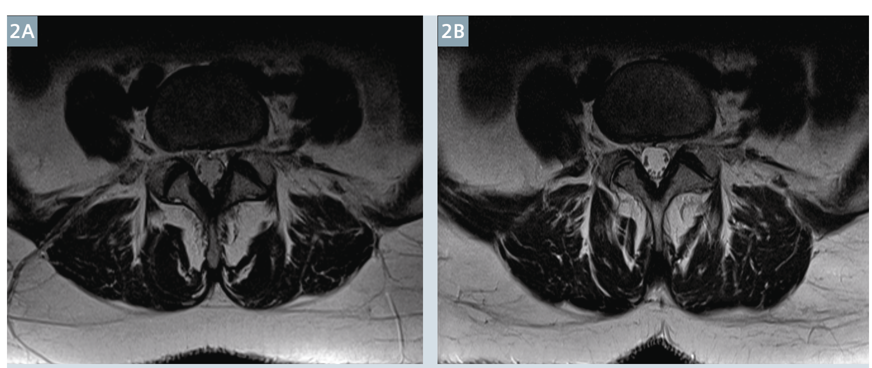
In 2007 the decision was made to acquire a MAGNETOM Avanto 1.5T MRI system (Siemens Healthcare, Erlangen, Germany). This scanner worked consistently over the years to provide very good image quality. Nevertheless, always aiming to optimize our image quality and performance, in 2013 we became one of the first MRI centers in Switzerland to perform a fit upgrade, accompanied by a Dot upgrade. Notwithstanding the acquisition of additional diagnostic tools during the first years (such as spectroscopy,



TR 4000 ms, TE 122 ms, TA 3 min, 12 slices, FOV 317 x 320, matrix 754 x 896, SL 4.0 mm

TR 3250 ms, TE 91 ms, TA 3:31 min, 15 slices, FOV 300 x 300, matrix 307 x 512, SL 4.0 mm

1 46-year-old female patient. T2w sagittal images of the lumbar spine, before **(1A)** and after **(1B)** MAGNETOM Avanto^{fit} upgrade. Note the improved image quality in 1B (i.e. better delineation of the nerve roots).



TR 3100 ms, TE 108 ms, TA 3:03 min, 15 slices, FOV 248 x 250, matrix 311 x 448, SL 4.0 mm

TR 3800 ms, TE 108 ms, TA 2:58 min, 16 slices, FOV 200 x 200, matrix 269 x 448, SL 4.0 mm

2 Same patient as in Figure 1. T2w axial images of the lumbar spine, before **(2A)** and after **(2B)** MAGNETOM Avanto^{fit} upgrade. In 2B note the possibility to reduce the FOV and therefore improved image resolution, in shorter acquisition time (i.e. the nerve roots).

perfusion imaging and susceptibility-weighted imaging), this fit upgrade was our first major MR upgrade.
A second major step has been our update to software version *syngo* MR E11C. A milestone in this context was our participation as a CPF ("Customer Preference Feedback") reference center for the *syngo* MR E11C software version in 2015/2016.

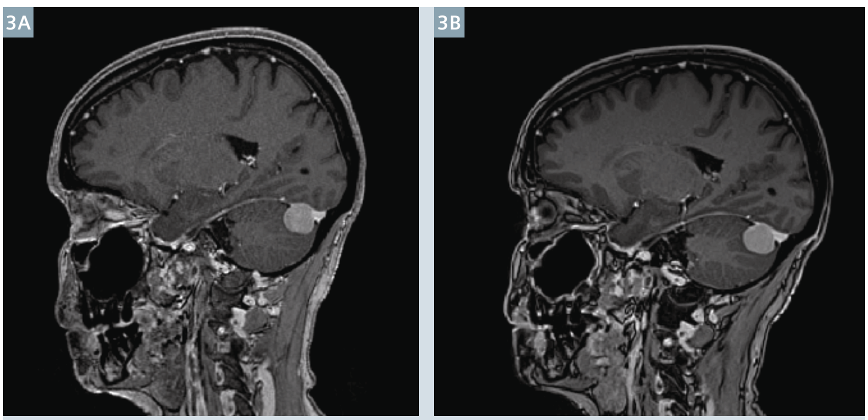
Avanto^{fit} and first Dot engine experiences

Despite the high image quality of the MAGNETOM Avanto system, we needed firstly to respond to our referring physicians' demands for the best image quality, and secondly to stay competitive as a leading MRI center amongst the increasing number of 3T systems available in the Zurich area. We decided on the Avanto^{fit} upgrade instead of buying a new scanner, a solution we thought would be more cost efficient and less time consuming. Since we have only one MRI scanner, we could not afford the time required for the de-installation and a new installation, whereas an upgrade would reduce the downtime of the system to a couple of days.

We decided to carry out this fit upgrade during the summer holiday season, when most of our referring physicians were on holiday. Following the fit upgrade installation we received one week's intensive support from our Siemens MR Application Specialist, since obviously an adjustment of all our sequence protocols was necessary. This intensive and time-consuming period after installation was followed by a two-month period of further protocol optimization, with the help of the application specialist, adapting the initial protocols after gaining some experience with the new system. In retrospect, all of our efforts were worthwhile.

The improvement of the image quality was obvious in all examinations over the whole body. External neurologists and orthopedic surgeons mentioned that our image quality was so good that they thought we bought a 3T-system (Figs. 1, 2).
This fit upgrade had two benefits of a 1.5T over a 3T system: Less susceptibility artifacts, specifically in abdominal imaging, as well as patient security and fewer limitations in case of intracorporeal medical devices such as prosthetic cardiac valves etc. This was definitively the right choice for our institution.

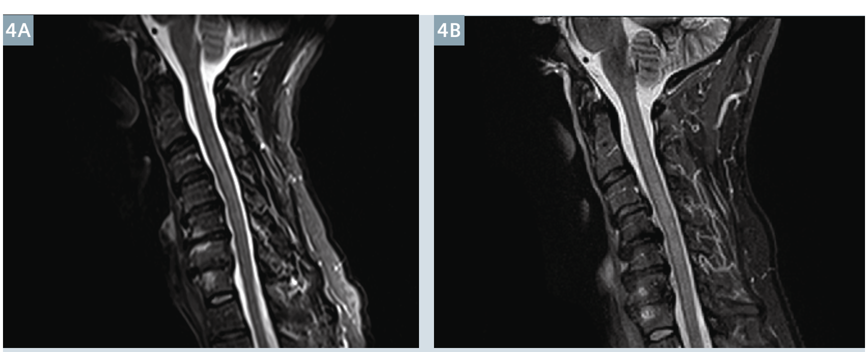
In brain-imaging specifically the 3D-MPRAGE-sequence became much crispier and clearer (Fig. 3) and the RESOLVE-diffusion showed significantly less artifacts in comparison to the standard EPI diffusion.
In spine-imaging we were able to reduce the field-of-view (FOV) and therefore increase the resolution with even higher signal-to-noise ratio (SNR) (Fig. 4). In shoulder-imaging, the new Shoulder 16-channel coil not only gave better image quality, but also increased patient comfort when positioned. In knee-imaging, the new 15-channel Tx/Rx Knee coil produced images of a quality superior to the previous system (Fig. 5). The only disadvantage is that obese patients and patients after trauma unable to stretch-out their knee do not fit into this coil: For those cases we still use the previous Extremity coil with an additional adapter in order to enable



TR 2060 ms, TE 3.4 ms, TI 1100 ms, TA 5:11 min, 208 slices, FOV 250 x 250, matrix 320 x 320, SL 0.9 mm

TR 2000 ms, TE 2.5 ms, TI 900 ms, TA 5:01 min, 208 slices, FOV 250 x 250, matrix 288 x 288, SL 0.9 mm

3 54-year-old female patient. 3D-MPRAGE-sequence of the brain after contrast administration before **(3A)** and after **(3B)** MAGNETOM Avanto^{fit} upgrade showing a meningeoma of the cerebellar tentorium. Note the much better image quality in less acquisition time in 3B (i.e. the delineation of the cortical matter).



TR 3500 ms, TE 91 ms, TA 3:27 min, 12 slices, FOV 280 x 280, matrix 384 x 512, SL 3.5 mm

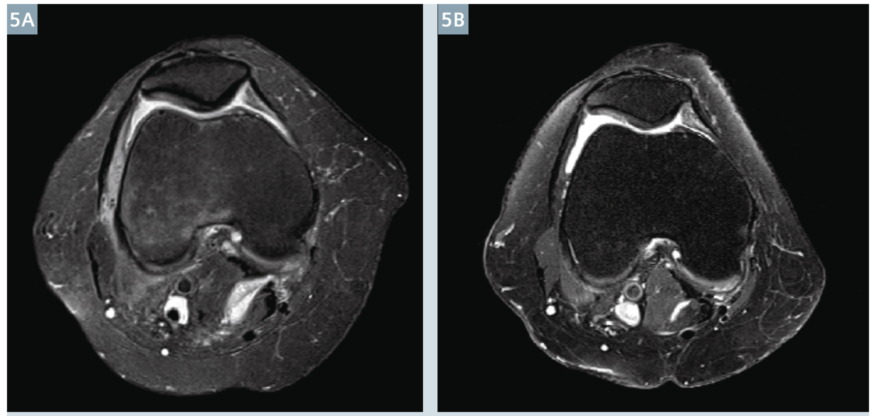
TR 3500 ms, TE 29 ms, TA 3:47 min, 12 slices, FOV 220 x 220, matrix 515 x 512, SL 3.0 mm

4 45-year-old male patient. STIR sagittal images of the cervical spine, before **(4A)** and after **(4B)** MAGNETOM Avanto^{fit} upgrade. Note the possibility to reduce both the FOV and the slice-thickness with minimal increase in acquisition time, and with a superior image quality in 4B (i.e. the subtle signal intensity changes of the spinal cord).

the link with the new system. Special mention should go to the Hand/Wrist 16 coil and Foot/Ankle 16 coil for their convenience for the patient and for enabling the scan of very small structures (such as a finger joint) or the whole hand, and the foot without moving the target area within the coil (for example imaging a distal joint or a proximal joint; Fig. 6).

Feedback from our technologists tells us that one of the advantages of the fit upgrade is the much easier handling of the coils with the new innovative SlideConnect system and the new in-room display at the scanner, which enables the technologist to get information about the coils before leaving the scanner room. Additionally the display provides patient-data-information, ECG-waves, etc.

Definitely one of the biggest steps of evolution and advantage of the new system is the standardization of the exam protocols using the Dot engines in routine examinations. The first Dot engines we used were the Brain and the Spine Dot Engines. The Brain Dot Engine, with AutoAlign, its automatic anatomic orientation, not only helps less experienced technologists to reliably find the anatomic landmarks for an optimal examination, but also guides the radiologist in the comparison of the image-planes in follow-up brain studies such as in multiple sclerosis patients, because of the identical slice orientation and slice-positioning.

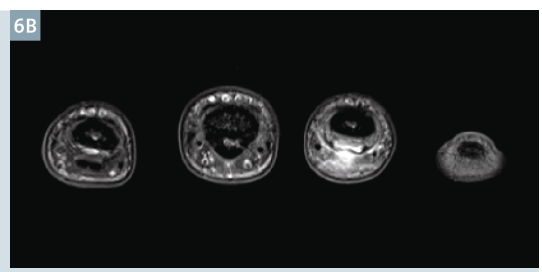


TR 2120 ms, TE 41 ms, TA 2:14:2 min, 32 slices, FOV 160 x 160, matrix 240 x 320, SL 3 mm

TR 3600, TE 45 ms, TA 3:10 min, 30 slices, FOV 160 x 160, matrix 269 x 448, SL 3 mm

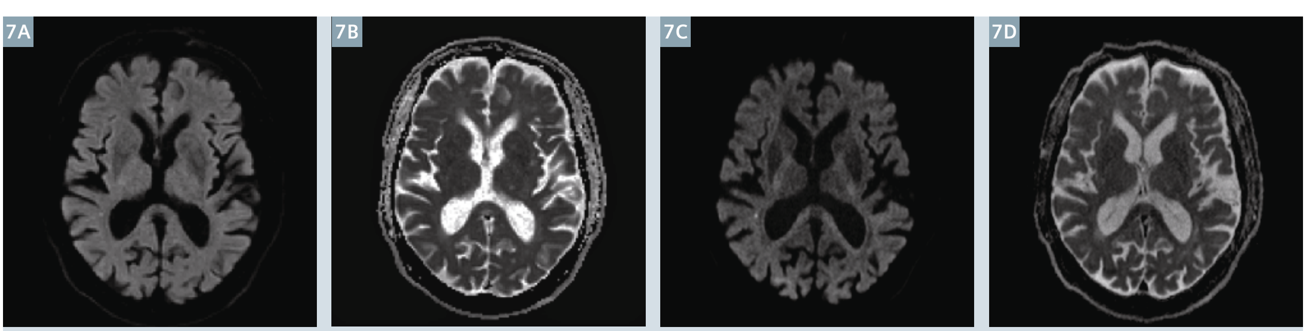
5 75-year-old female patient. Proton Density-weighted fat sat (PDfs) axial images of the knee before **(5A)** and after **(5B)** MAGNETOM Avanto^{fit} upgrade, using the new 15 channel knee coil. Note the much better image quality in 5B (i.e. in the retropatellar cartilage).

TR 3010 ms, TE 26 ms, TA 2:09 min, 20 slices, FOV 186 x 220, matrix 345 x 512, SL 2 mm



TR 4200 ms, TE 28 ms, TA 3:31 min, 25 slices, FOV 96 x 110, matrix 353 x 448, SL 3 mm

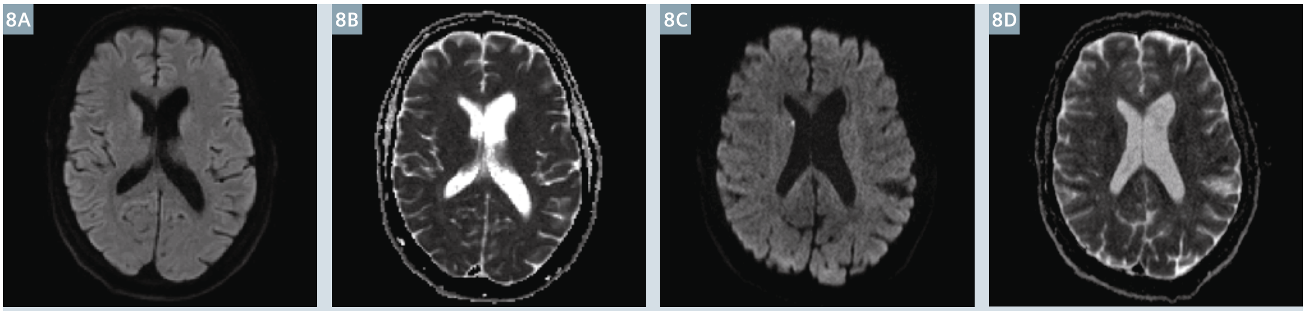
6 15-year-old male patient with rupture of the flexor digitorum profundus tendon (4th finger). Note the high quality images: **(6A)** Coronal PDfs image showing the rectracted tendon and **(6B)** axial PDfs image showing the empty space, where the tendon should be.



TR 4000 ms, TE 64 ms, SL 5 mm, TA 1:34 ms, 25 slices, b-value 1000

TR 3000 ms, TE 83 ms, SL 2.5 mm, TA 2:40 ms, 40 slices, b-value 2000

7 71-year-old male patient with focal acute embolic ischemia within the Meyer's loop on the right hemisphere (standard RESOLVE Diffusion **(7A)** b1000 image, **(7B)** ADC map). Note the much better visibility of the pathology using thinner slices and higher b-value (modified SMS-Diffusion **(7C)** b2000 image, **(7D)** ADC map). Because of the Simultaneous Multi-Slice acquisition, the image quality is very good **(7C, D)**, even with a b-value of 2000. (Also see Table 1.)



TR 4000 ms, TE 64 ms, SL 5 mm, TA 1:34 ms, 25 slices, b-value 1000

TR 3200 ms, TE 83 ms, SL 2.5 mm, TA 2:51 ms, 40 slices, b-value 2000

8 56-year-old male patient with focal acute lacunar infarct in the head of the right caudate nucleus, only visible in the modified SMS-Diffusion sequence **(8C, D)**. No visibility of the pathology at all in the standard 5 mm RESOLVE diffusion **(8A, B)**. Standard RESOLVE Diffusion **(8A)** b1000 image, **(8B)** ADC map; modified SMS-Diffusion **(8C)** b2000 image, **(8D)** ADC map. (Also see Table 1.)

The Spine Dot Engine was very useful in ensuring a complete coverage of the spine, even for patients with scoliosis. The automatic labelling of the axial slices is very much appreciated by our referring spine-surgeons, helping them to look quickly through the images even as hard-copy films, which many of them still share and discuss with their patients, rather than the primary images taken from CD.

Update to *syngo* MR E11C

The update to the new software version *syngo* MR E11C has had profound benefits for our team. Whilst we faced major software layout changes, we also benefited from new possibilities and opportunities by using the new workflow and a number of new Dot engines.

Perhaps the most important improvement in image quality due to *syngo* MR E11C is simultaneous multi-slice (SMS) diffusion-imaging. Realizing the possibilities of high SNR and time-efficiency of this sequence, one of our first modifications for brain imaging was to create a 2.5 mm thin sliced sequence with a b-value of 2000 s/mm^2. This modification was initially scrutinized by the Siemens-developers, who were quickly convinced of the advantages of this modification. With such a high b-value the conspicuity of acute ischemic lesions increased dramatically. Using the very robust RESOLVE diffusion (b-value 1000 s/mm^2, 5 mm slice thickness) as a standard sequence, we sometimes doubted the interpretation of our findings as to whether or not there was an ischemic lesion. However, using the modified SMS-diffusion, we were able to eliminate these doubts in all cases. Therefore this sequence found its way into our standard stroke protocol (Figs. 7, 8, Tab. 1).

	Original parameters	Parameters for SMS Diffusion in stroke protocol
Voxel size (mm)	0.6 x 0.6 x 4.0	0.6 x 0.6 x 2.5
PAT	4	4
Accelerator factor slice	2	2
Slices	28	40
Position	Isocenter	L2.8 A26.4 H21.7 mm
Orientation	Transversal	T > C-4.1 > S-2.1
FOV (mm)	220	230
Slices (mm)	4	2.5
TR (ms)	4000	3200
TE (ms)	97	83
Coil elements	HE 1-4	HE 1-4; NE1,2
AutoAlign	–	Head > Brain
Initial position (L x P x H) (mm)	Isocenter	0 x 17 x 2.8
System adjustments		
B1 Shim mode	TrueForm	None
Diffusion mode	4-scan trace	4-scan trace
Diffusion scheme	bipolar	monopolar
Diffusion-weightings		
b-value 1	0 s/mm^2	0 s/mm^2
b-value 2	1000 s/mm^2	2000 s/mm^2
Sequence part 1		
Echo spacing (ms)	1.04	0.91
Bandwidth (Hz/Px)	1042	1240
TA (min)	1:17	2:51

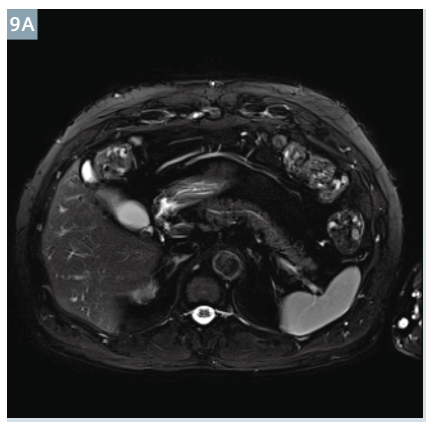
Table 1: Modified parameters of Simultaneous Multi-Slice (SMS) Diffusion for standard stroke protocol.

A substantial improvement of the new *syngo* MR E11 software has been the new ability with the Dot Cockpit to create and combine Dot protocols in a definitively easier way than in prior software versions. With a basic instruction we were able to create our own new Dot-protocols, according to our local needs, without reliance on an application specialist.

Initially, the acceptance of the Abdomen Dot Engine was suboptimal: being used to manually adapting the positioning of various parameters (e.g. slice, slab, FOV etc.) to the patients' anatomy and cooperation, we had to learn a more passive role during the acquisition of the examination. Nevertheless, the vast advantages of a guided workflow and automatic adaption of field-of-view and number of slices to the individual anatomy with AutoCoverage soon convinced us – especially for the liver. Less experienced technologists in particular appreciated the automatism for the more challenging abdominal studies. The automatic breathing commands in the Dot Engine allowed us to standardize the timing of our arterial phase in liver imaging by using the bolus-tracking technique with automatic bolus detection, thereby enabling us to acquire a consistent arterial phase, independent of patients' cardiac output. This contrast phase stability has been particularly useful in the follow-up of patients with liver cirrhosis and screening for hepatocellular carcinoma. As to time-efficiency, the new fast BLADE technique allowed a much quicker T2 acquisition of the liver, especially when using a gated technique (Fig. 9), and the coronal T1 3D acquisition became much faster by using FREEZEit and the StarVIBE (T1 VIBE CAIPIRINHA) technique. The DynaVIBE offers the possibility of multi-arterial phase acquisition, although some institutions prefer only one well-timed arterial phase with bolus-tracking. The StarVIBE technique minimizes breathing artefacts, and is especially useful with patients who are not able to hold their breath, or deaf patients. This was also one of the sequences we modified with the assistance of Siemens creating a test-version[1] of a dynamic StarVIBE sequence, which enabled dynamic liver imaging with decent image quality even with totally uncooperative patients (Fig. 10, Tab. 2). Liver-evaluation techniques with quantification of fat and iron-deposition within the liver are completing an advanced evaluation of liver pathologies.

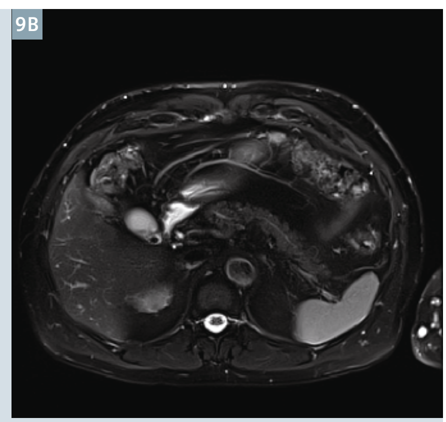
A new innovative technique with the potential to revolutionize MR-Angiography is the Quiescent-Interval Single-Shot (QISS) sequence. This is the first reasonable alternative to contrast-enhanced angiography, in particular peripheral angiography

[1] WIP, the product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured.



9A

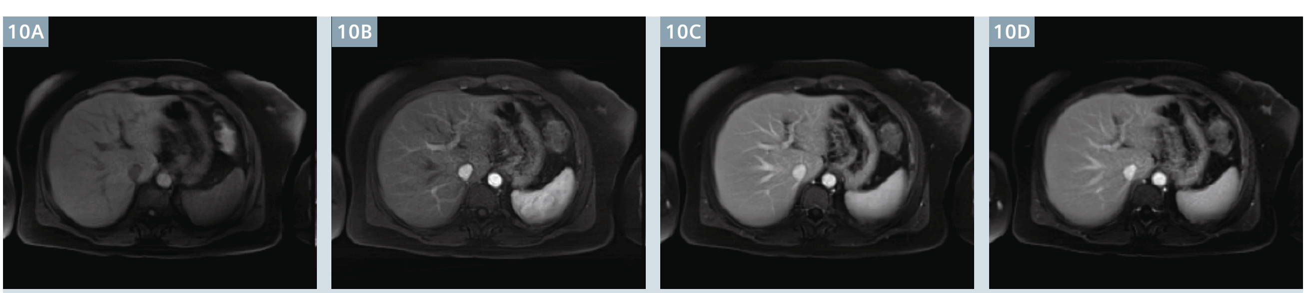
TR 5325.3 ms, TE 96 ms, TA 46.06 x 5, FOV 380 x 380, matrix 320 x 320, SL 6 mm



9B

TR 5274.1, TE 83 ms, TA 22.77 x 5, FOV 380 x 380, matrix 320 x 320, SL 6 mm

9 Abdominal imaging of a 64-year-old male patient. Comparison between T2w fs-acquisition of the liver with gated T2 BLADE **(9A)** and T2w fast BLADE technique **(9B)**. Note the sharper image contrast and better visibility of the gallbladder stone in less than half of the time in T2w fast BLADE in **9B**.



10A 10B 10C 10D

TR 3.3 ms, TE 1.4 ms, TA 21.35 sec, SL 4 mm, FOV 380 x 380

10 46-year-old female patient, immigrant, unable to understand the language in which the breathing commands were spoken. Modified StarVIBE sequence was used to acquire dynamic imaging before and after contrast-enhancement: **(10A)** without contrast medium, **(10B)** late arterial phase, **(10C)** first hepatovenous phase, **(10D)** second hepatovenous phase. Note the sharp organ contours and the well delineated anatomic structures without breath-hold imaging in different phases (each phase less than 22 seconds). (Also see table 2)

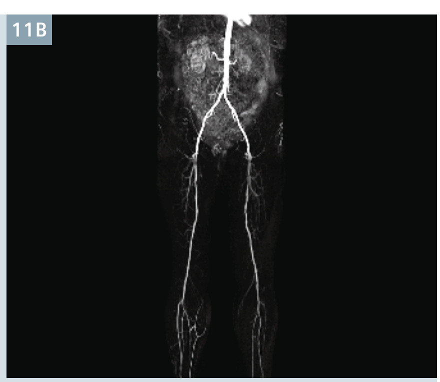
	Original parameters	Parameters for T1 StarVIBE dynamic liver imaging
Voxel size (mm)	1.2 x 1.2 x 3.0	1.7 x 1.7 x 4.0
Slab group		
Position	Isocenter	Isocenter
Orientation	Transversal	Transversal
Rotation	0.00 deg	90 deg
Phase directions	A - P	R - L
Slice oversampling	44.5%	0.0%
Slices per slab	72	52
FOV (mm)	380	380
Slice thickness (mm)	3	4
TR (ms)	2.83	3.26
TE (ms)	1.48	1.44
Flip angle	9 deg	10 deg
Lines per shot	56	18
Coil elements	BO1-3;SP2,3	BO1-3;SP2-4
Contrast – Dynamic		
Multiple series	Each measurement	Off
Resolution		
Base resolution	320	224
Radial views	680	220
System adjustments		
B1 Shim mode	TrueForm	Off
Sequence part 1		
Bandwidth (Hz/Px)	820	600
Sequence Assistant		
Allowed delay	60 s	–
TA (min)	2:53	0:21

Table 2: Modified parameters for dynamic liver imaging for totally uncooperative patients.

of lower extremity arteries (Fig. 11). Furthermore the QISS sequence can visualize arterial vessels in the lower leg each time without any overlay of venous vessels, which may happen in contrast-enhanced angiography. Knowing the adverse effects of contrast-media discussed in recent years, such as nephrogenic systemic fibrosis (NSF) and gadolinium accumulation in the brain, and having recently had the personal experience of a very rare life-threatening anaphylactic shock due to gadolinium administration, we do appreciate any development in this direction.

Summary

Our long-term experience with MR upgrades is a real success story. Technical innovations lead to better image quality and faster examination protocols, help improve the comfort and safety of the patients through the MR-examination, and especially help increase the radiologists' confidence in the final diagnosis. Therefore, an increased image quality that convinces the referring physician is an improvement in the quality of our product that we hope will lead to a better patient outcome.



TR 544.4, TE 1.7, TT 475.0, TI 345.0

TR 3.0, TE 1.0

11 71-year-old female patient. Comparison between MR Angiography (MRA) with QISS technique without intravenous contrast administration **(11A)** and MRA with intravenous contrast administration (gadobenate dimeglumine) **(11B)**. Note the comparable image quality in **(11A)** without intravenous contrast. One of the additional benefits of the QISS technique is the lack of overlapping venous artifacts as seen sometimes in contrast-enhanced MRA.

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